1985

In Search of Predatory Pricing

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Comments
This article was originally published in *Journal of Political Economy*, volume 93, issue 2, in 1985.

In Search of Predatory Pricing

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Can predatory pricing be reproduced in a laboratory environment? We report research motivated by this objective. We began with conditions that, based on the literature, appeared to combine the features this literature has suggested are favorable to the emergence of predation. Next we operationalized what was meant by predatory pricing in our design in order to compare prices with predictions from alternative theories. Of 10 experiments, none evidenced predatory behavior; most supported the dominant firm theory. The second series of experiments addresses remedies for predation and finds that the effect is to increase prices and reduce efficiency.

I. Overview of Research Procedure and Results

Is predatory pricing an observable phenomenon that can be induced in a laboratory environment? We report research motivated by the maintained hypothesis that if such behavior is a human trait we ought to be able to observe it in the laboratory. Our procedure was first to specify a set of structural conditions that appeared to us to combine those features that were favorable to the emergence of predatory behavior: (1) two firms—one large, one small; (2) scale economies, with the larger firm having a cost advantage over the smaller (but with the smaller firm's production required for market efficiency); (3) a "deep pocket" possessed by the advantaged firm; and (4) sunk entry costs tending to discourage reentry when such costs must be incurred. Next we constructed an experimental design to operationalize these conditions and to define predatory pricing within this design. In this

We gratefully acknowledge the financial support of the Federal Trade Commission and the research assistance of David Porter, Mark Olson, and Peter Knez.

[*Journal of Political Economy*, 1985, vol. 93, no. 2]

design, predatory prices are distinct from several alternatives: competitive prices, the shared monopoly price, the dominant firm price, and Edgeworth-style price cycles.

Our first three experiments were conducted with attributes 1–3. The second series added feature 4. After six experiments, we still had not observed predatory pricing. A reconsideration of the literature suggested that most predatory pricing theories implicitly assumed a fifth feature: (5) firms have complete information about competitors' costs. Although we do not consider complete information a realizable field condition in most (if any) markets, we decided this condition should be included in the search for predatory pricing behavior. Our third series of experiments, incorporating conditions 1–5, still produced no evidence of predatory pricing. Because some scholars have suggested that predatory pricing, if it exists, is driven by goals other than profit maximization, we attempted, without success, to generate "cut-throat" pricing in one experiment by inducing rivalistic incentives. At this point we wondered if there were something artifactual about our experimental design that, unsuspected by us, would inhibit the small firm's being driven out of the market even if the large firm posted prices and quantities below marginal cost. For example, do subjects who are assigned the small firm's structural conditions perceive themselves as duty bound to remain in the market? If this were the case, then the predicted effect of predation would not be observed, even if we did observe predatory price levels quoted by the large firm. So we conducted one experiment in which, unknown to the small firm, the large firm was a confederate of the experimenters and was instructed to price repeatedly at predatory levels. This prompted the small firm to leave the market, and therefore we were confident of our small firm's vulnerability to being forced out of the market by a determined predator.[1]

The second part of the research program had the objective of examining proposed antitrust remedies for predatory pricing that might be imposed on an industry thought to be subject to predation. For our antitrust treatment condition, we applied a semipermanent price reduction rule (Baumol 1979) and a quantity expansion limit (Williamson 1977). We conducted seven experiments (series 6) with attributes 1–4 and with these two antitrust restrictions. Since no predation was found in the 11 experiments based on conditions 1–4

[1] While the negative results of the 11 experiments we report cannot prove that predatory pricing does not exist, we feel that they alter the burden of proof for those who would design public policy as though predation were a robust phenomenon. We invite antitrust scholars to scrutinize our experimental design, to suggest specific ways in which they would alter it, and to state the corresponding outcomes they are prepared to predict. We will take their suggestions seriously.

TABLE 1

CLASSIFICATION OF EXPERIMENTS

TREATMENT SERIES NO.	NO. OF REPLICATIONS	TREATMENT CONDITION					EXPERIMENT NUMBER(S)
		Entry Cost	Complete Information	Induced Rivalry	Confederate	Antitrust Rules	
1	3	No	No	No	No	No	129, 131, 133
2	3	Yes	No	No	No	No	135, 136, 138
3	3	Yes	Yes	No	No	No	139, 140, 141
4	1	Yes	No	Yes	No	No	142
5	1	Yes	No	No	Yes	No	143
6	7	Yes	No	No	No	Yes	145, 146, 147, 149, 150, 152, 153

alone, we interpret this series of seven experiments as a test for the existence of type 2 regulatory error, that is, whether adopting anti-predatory pricing rules might induce anticompetitive incentive effects.

Table 1 summarizes the treatment conditions underlying the experiments in each of the series 1–6.

II. Predatory Pricing: From the Literature to Experimental Design

The idea that there is a distinction to be made between the price that is low because of good competition and the price that is low because of bad predation is well established in American legal and political history. It appears in early Supreme Court decisions subsequent to the enactment of the Sherman Act (e.g., *Trans-Missouri Freight* case and *Standard Oil* case).[2]

Economists J. B. and J. M. Clark, in a book chapter subtitled "Destructive Competition," describe a process of selective price cutting that is similar to the contemporary concept of predatory pricing, and Senator Estes Kefauver, prominent in the development of modern congressional antitrust policy, has mourned the passage of the era of "independent" bakeries.[3] Private antitrust cases and threats of litigation flourish. Of course, the existence of such cases does not necessarily demonstrate the existence of predation, since there clearly are other incentives for firms to assert that they are victims of predation.[4]

[2] U.S. v. Trans-Missouri Freight Association, 166 U.S. 290, 328 (1897). The court suggested that monopolization may involve strategic price reductions that may drive out of business "the small dealers and worthy men whose lives have been spent therein and who might be unable to readjust themselves to their altered surroundings." Standard Oil Company of New Jersey v. U.S., 221 U.S. 1 (1911). In this case the court implied that predation had replaced productive forms of business behavior: "The very genius for commercial development and organization which it would seem was manifested from the beginning soon begot an intent and purpose to exclude others which was frequently manifested by acts and dealings wholly inconsistent with the theory that they were made with the single conception of advancing the development of business power by usual methods, but which on the contrary necessarily involved the intent to drive others from the field and to exclude them from their right to trade and thus accomplish the mastery which was the end in view."

[3] This chapter is contained in Clark and Clark, *The Control of Trusts* (1912). Lest anyone confuse destructive competition with healthy price rivalry, they (p. 98) call such practices "refined forms of robbery" and demand that "the illegitimate breaking of a general scale of prices must, in some way, be stopped." Sen. Kefauver states (1965, p. 139) that many independents "personally know small bakers who have been destroyed by engaging in competitive warfare with the majors."

[4] In International Air Industries et al. v. American Excelsior Company, 517 F.2d 714 (1975), *cert. denied,* 424 U.S. 943 (1975), predation was alleged in the "evaporative-cooler pad" industry. The courts rejected the claim, stating, "It would appear that [the defendant] was selling its cooler pads at a price far above even its average cost. More-

Our task in the present research was to operationalize the concept of predation into a reasonable economic design with testable predictions. Our goal was to create an economic environment that we felt would have a "best shot" at observing predatory pricing. Unfortunately, we found no single universally accepted model of predatory pricing. However, we were able to identify several important design elements to use in some or in all of our experiments.

The trading environment we chose for our investigation is that of firms producing to order a homogeneous product for sale in a posted-offer market with full demand revelation.[5] Other design features were identified from our reading of the literature in predatory pricing. These are presented in the paragraphs below. Finally, in the last seven experiments, we conducted the markets with a predatory pricing antitrust program (PPAP), which is described in paragraph 7 below.

1. *Number of firms.* Every source we consulted spoke of predation by a single predator. However, the prey may be singular (Salop 1981, p. 11) or plural (Scherer 1980, p. 335; Kreps and Wilson 1982; Milgrom and Roberts 1982; Selten 1978). Because of our previous experience with two-firm markets (Coursey, Isaac, and Smith 1984; Coursey, Isaac, Luke, and Smith 1984; hereafter CIS and CILS), we decided to continue with this design feature. In this case, however, the two firms were not symmetric in costs.

2. *Costs of the firms.* The literature appears to be in disagreement whether predator and prey are to be distinguished by costs. Some (McGee 1958, p. 140) say no. Others (Ordover and Willig 1981, p. 308; Salop 1981, p. 19) seem to suggest that while costs may be equal, they also may not. Still others build predation models explicitly around the concept of a dominant firm that has some cost advantage (Gaskins, as quoted in Scherer 1980, p. 338). Our previous experiences (CIS, CILS) with the symmetric cost case were marked by a complete absence of any success of one firm in achieving unchecked

over, the record indicates that barriers to entry in the cooler pad market were virtually non-existent." This is not to indicate that the court ignored marginal costs. They seem to be following an Areeda and Turner (1975) model in which average cost is used in certain instances as a proxy for the more important (but less observable) marginal cost. With regard to the issue of entry costs, the court estimated that "the total costs of entering the market on a scale large enough to supply the entire southwestern and far western United States" was less than $300,000.

[5] The made-to-order nature of production does not allow for carryover of stock from one period to another, and it eliminates the costs and risks of holding unsold stock. This ensures that the induced marginal cost schedules generate replicated periods with identical well-defined (flow) supply conditions. To our knowledge the literature nowhere suggests that predation is related to production for inventory.

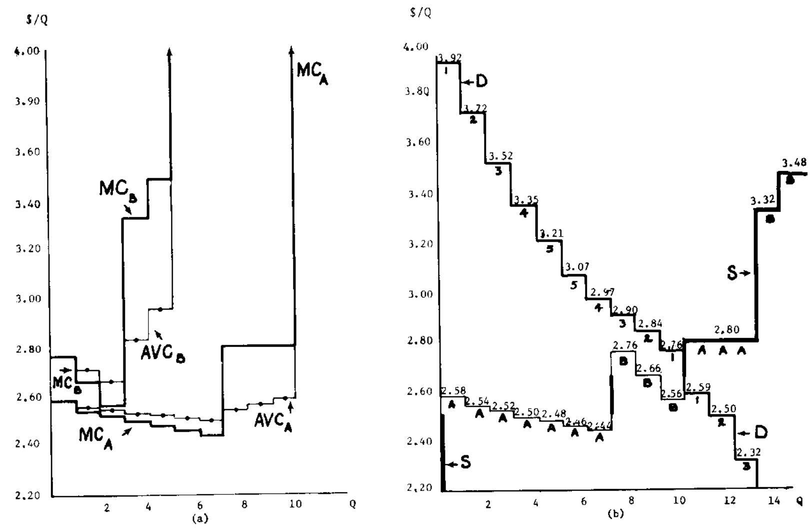

FIG. 1.—Seller costs, buyer values, and supply and demand conditions

monopoly power. Therefore, in order to create conditions more favorable to obtaining predation, we chose to give the predator an important cost advantage over the prey (hereafter called the "large" or "small" firm), but the small firm, although perhaps disadvantaged in our design, is efficient enough to be in production at a Pareto-efficient competitive equilibrium (Kefauver 1965, p. 144; Ordover and Willig 1981, p. 308).

These cost conditions were obtained via the induced seller marginal cost schedules exhibited in figure 1*a*. Figure 1*b* exhibits the market supply and demand conditions. From figures 1*a* and 1*b* several important attributes of our laboratory market can be noted. At the competitive equilibrium ($P_c \in [2.66, 2.76]$) both firms are producing. Seller A sells 7 units while seller B sells 3 units. Furthermore, there exist combinations of price and quantity for seller A ($2.60 \leqslant P_A < 2.66$; $8 \leqslant Q_A \leqslant 10$) such that seller A can exclude seller B from the market and yet earn a positive cash flow of returns from the experimenters.

3. *Deep pocket.* Many sources describe the predator as having a capital market advantage over the prey via what is popularly described as a deep pocket. The *Wall Street Journal* (1983) says of an FTC decision: "Critics of the agency say the new formula will let Borden price ReaLemon below its true costs in areas where Borden faces competition, while making up the difference in areas where ReaLemon enjoys

a monopoly." This is almost a twin argument to a hypothetical situation described by Clark and Clark (1912, p. 97).[6] Scherer (1980) quotes Edwards as saying of the predator, "the length of its purse assures it of victory." Scherer says directly of the predator, "it subsidizes its predatory operations with profits from other markets." Salop (1981, p. 11) defines the deep pocket as the case "in which an incumbent predator has superior access to financial resources." The idea is also mentioned by Kefauver (1965, pp. 146–49). We provided a deep pocket in the following manner: Since economic losses were a real possibility in our design, each seller was provided an up-front capital endowment. However, in all cases the endowment to seller A (the potential predator) was double the endowment to seller B. (Also, firm A's pocket was further deepened under treatment 4 below, which gives firm A the advantage of incumbency, as an uncontested monopolist, for the first 5 periods of each experiment.)

4. *Sunk cost entry and reentry barriers.* A common theme in the descriptions of conditions favorable to predators is the requirement that the small firm face barriers to entry or reentry. This raises the separate but related issue of what constitutes an effective barrier to entry. The contemporary debate on the contestable markets hypothesis concerns whether economies of scale alone can fulfill this requirement. If economies of scale do serve as an effective barrier, then our design features 1, 2, and 3 above might be sufficient to provide requisite hurdles. However, our previous research (CIS and CILS) suggests that scale economies alone might not provide a sufficient barrier to entry. Therefore, as an additional potential entry barrier, we add a fourth item suggested by Ordover and Willig (1981, p. 305), namely, sunk cost of entry or reentry. Furthermore, we require, at the time the small firm is making its entry decision, that the large firm should have an incumbency advantage that entails some privately held knowledge about the nature of demand and an initially irreversible commitment of already having "sunk" the entry cost. (See also Salop 1981, pp. 16–20.)

The sunk entry cost was obtained, as in CILS, by requiring sellers to purchase an entry permit before each was allowed to participate in the market. Permits cost $1.00 each and were good for only 5 consecutive periods. At $1.00 each, the permit charge represents two-thirds of the small firm's maximum 5-period earnings at competitive prices. To create the incumbency advantage, the experiments with this design feature opened with seller A required to purchase two

[6] But see Brozen (1982, pp. 330–33) for a well-documented compilation of arguments skeptical of the cross-subsidization, deep-pocket, entry barrier hypothesis. Among the quotes are two from Scherer.

permits good for periods 1–10. Seller B was not allowed the option of entering until period 6. Thus, at the point when seller B had to make an initial entry decision, seller A had irrevocably sunk enough costs to be in the market for (at least) 5 more periods. Also at the beginning of period 6, seller A had a 5-period advantage in obtaining private information about market demand and in deepening his purse.

5. *Information.* Much of the literature makes no explicit reference to the information available to the firms, yet most appear to assume implicitly that firms have complete information about each other's costs. (Exceptions are found in Salop [1981], Kreps and Wilson [1982], and Milgrom and Roberts [1982].) In most of our experiments, the firms did not know one another's cost structure and neither knew demand. However, in three experiments we introduced complete cost information. In these experiments, participants had been in a previous predatory pricing experiment (although not with one another). Each was assigned the opposite of his previous position (so as to have sellers who knew what it was like to be on the other side), and each was given a written table of the other's costs (to refresh their memory).

6. *Rivalry.* Implicit in many of the discussions of predation is the issue of intent. If we cannot distinguish predatory from healthy forms of competition on the basis of performance variables, then intent is a logical direction for attempts at a distinction to take. Unfortunately, an intent-based standard is highly subjective.

In one of our experiments, we introduced a treatment distinction between the large firm's normal desire to exclude the smaller firm (based on a presumed profit-maximizing calculus) and a desire to exclude based on a rivalistic, abnormal intent. When this rivalistic feature is in effect, the large firm is told privately that it will receive a $1.00 cash bonus for each period in which the smaller firm chooses not to enter the market. In effect we attempt to induce a direct utility to A for excluding B, which is motivated by the conjecture that predation may occur but not spring from a profit-maximizing intent.

7. *Predatory pricing antitrust program (PPAP).* Our final seven experiments were conducted with this PPAP in place. This was operationalized in two parts. First, the incumbent firm faced an output expansion limit. Whenever the smaller firm entered the market (i.e., seller B bought a permit in period t when he or she did not have a permit in period $t - 1$), seller A could not expand his or her maximum quantity offered for sale for 2 periods. Second, the incumbent faced a semipermanent price reduction regulation. During any of the periods in which seller B could be in the market, all of seller A's price reductions (if they occurred) had to be maintained for at least 5 consecutive periods.

III. The PLATO Posted-Offer Procedure

Most retail markets are organized under what has been called the posted-offer institution (Plott and Smith 1978). As we define it, in this institution each seller independently posts a take-it-or-leave-it price at which deliveries will be made in quantities selected by each individual buyer subject to seller capacity limits. These posted prices may be changed or reviewed frequently, infrequently, regularly, or irregularly, but in any case a central characteristic of this mechanism is that the posted price is not subject to negotiation.

The experiments reported here use the posted-offer mechanism programmed for the PLATO computer system by Ketcham (see Ketcham, Smith, and Williams 1984). This program allows buyers and sellers, sitting separately at PLATO terminals, to trade for a maximum of 25 market "days" or pricing periods. Each display screen shows that subject's record sheet, which lists the maximum units that can be purchased (sold) in each period. For each unit, the buyer (seller) has a marginal valuation (cost) that represents the value (cost) of purchasing (selling) that unit. These controlled, strictly private, unit valuations (costs) induce individual and aggregate market theoretical supply and demand schedules (Smith 1976). That is, in an experiment, buyers (sellers) earn cash rewards equal to the difference between the marginal value (selling price) of a unit and its purchase price (marginal cost). Sales are "to order" in the sense that there are no penalties or carryover inventories associated with units not sold (or units not purchased). Consequently the assigned marginal valuations and costs induce well-defined flow supply and demand conditions.

Each period begins with a request that sellers select a price offer by typing a price into the computer keyset. This offer is displayed privately on the seller's screen. The seller is then asked to select a corresponding quantity at that offer price. Because the essence of the predatory pricing hypotheses is that a seller may have a strategic reason for pricing below marginal cost, the program we utilized placed no restriction except for an ultimate capacity constraint on what combination of prices and quantities any seller was permitted to post.

Since it is time and effort costly for a seller to calculate the profit that any given offer may provide, especially with U-shaped costs, PLATO always informs the seller of the potential profit (loss) if all offered units are sold. When satisfied with the selected price and quantity, the seller presses a touch-sensitive "offer box" displayed on the screen. This action places that seller's offer irrevocably into the market. Before touching the offer box the seller may change the price and/or quantity as many times as desired. Each seller sees the prices posted by the other seller only after both have entered their offers by touching the offer boxes.

Because virtually all of the hypotheses regarding predatory pricing explicitly or implicitly assume that buyers act to fully reveal market demand, we needed to incorporate this feature into all 18 of our experiments. To do this, we used the computerized buyer subroutine that had proved successful in previous research (CILS 1984). After both sellers entered their offers, PLATO randomly ordered each of the five buyers in figure 1 into a buying sequence, just as with human subject buyers. However, the purchasing decisions were made by a PLATO program with the buying rule that demand was fully revealed. That this computerized response would take place, and that the buyers would purchase all that was profitable to them at the given prices, was explained to the sellers so that it was not credible for sellers to harbor even the expectation that demand might be underrevealed. A trading period ended when the last buyer completed this buying mode. Sellers were not told what the final period of the experiment would be.

There is no difference in physical surroundings or computer interaction depending on whether or not a seller has purchased an entry permit. This was done to minimize any extraneous incentives to purchase or not to purchase a permit. A seller who chooses not to purchase an entry permit remains at the terminal, watching the prices posted by the other seller. Since this is a posted-offer market, sellers with and without permits are equally passive in computer terminal responsibilities once the market has opened to the buyers.

IV. Alternative Hypotheses

Predatory pricing is a hypothesis about firm behavior under certain structural conditions, which, according to our interpretation, is represented by specifications 1–5 in Section II. However, in addition to the predatory pricing literature, an extensive oligopoly literature has identified many other hypothesized modes of pricing behavior when numbers are few. Because we could not be sure that we would observe predatory behavior, it was necessary for us to consider alternatives that we might observe under conditions thought to favor such behavior. This necessity was underlined when the first few experiments failed to yield predatory pricing, and therefore early in the search process we were motivated to specify alternative outcome hypotheses. Although the literature was helpful in suggesting alternative hypotheses we do not find it helpful in providing a coherent, clear delineation of the conditions necessary to yield each of the various modes of pricing behavior. In view of this we decided to err on the side of overspecification by assuming that any behavioral hypothesis might apply as long as it assumed that one or both firms choose prices. This seems to rule out only the Cournot quantity-adjuster model of oligopoly.

A. *Predatory Pricing*

Based on the literature summarized in Section II above there are two elements in the definition of predatory pricing. First, the price charged by the predator is lower than would be optimal in a simple myopic (short-run) pricing strategy. Second, the price has the effect of preventing entry, or driving out and preventing reentry, of the prey. In our experimental design if there is a predator we expect it to be firm A, with firm B the prey, since we assume that predatory action by firm B would be suicidal and that the agent for firm B will become aware of this assessment. Therefore, we interpret the first element to mean that $P_A(Q_A) < MC_A(Q_A)$, where $P_A(Q_A)$ is the inverse demand function, and the second element to mean that $P_A(Q_A) < \min AC_B(Q_B)$. For seller A in our design, price offers below \$2.66 are potentially predatory, depending on the quantity offer chosen by A. For example, if seller A posts a price of \$2.64 but limits the quantity offered to 7 units, then $P_A(7) > MC_A(7)$, and this strategy leaves some (contingent) excess demand in the market for firm B to satisfy at a higher price. We define a predatory action by seller A to be a posted price less than \$2.66 accompanied by the selection of a quantity of at least 8 units. Thus, a predatory action is defined by the choice ($P_A \in [\$2.60, \$2.65]$, $Q_A \geqq 8$) since this yields $P_A(Q_A) < MC_A(Q_A)$ and $P_A(Q_A) < \min AC_B(Q_B)$. Since $P_A(Q_A) > AVC_A(Q_A)$, this predatory action still generates a positive profit for firm A; our design is deliberately rigged to allow firm A to predate without imposing a loss on himself. Consequently, although there is a short-run opportunity cost of predation to the predator there is no net out-of-pocket loss.

In summary, if we observe firm A choosing predatory prices and quantities that conform to this definition followed by firm B exiting and not reentering even when firm A subsequently increases its price, we will count such an observation as supporting the predatory pricing hypothesis. However, if we observe firm B exiting the market and electing not to reenter in response to price cutting by firm A that is not predatory, we will interpret this to mean that firm B is particularly vulnerable to price-cutting actions, and we will still count such an observation as supporting the predatory pricing hypothesis. Behavior of this type would suggest that firm A had established a credible predatory threat to firm B without pricing in the defined predatory range.

B. Competitive Equilibrium

If predatory behavior is manifest, but it fails to eliminate the small firm from the market, the result may be to spoil any effective tacit cooperative coupling between the two firms. Hence, the competitive equilibrium may prevail, as a default outcome, from the failure of predatory attempts. Alternatively, price cutting may be less severe than the predation model suggests but be sufficient to lock the two firms into the competitive equilibrium. The extensive experimental evidence favoring the competitive equilibrium, under different trading institutions, when numbers are few suggests a strong a priori case for this hypothesis in the present design. In this design, competitive equilibria are defined by $Q_A = 7$, $Q_B = 3$, and prices in the interval [2.66, 2.76].

C. Dominant Firm Equilibrium

If firm B is assumed to be a price taker, or adapts to its disadvantaged position by becoming a price taker, then a possible outcome is that of the dominant firm equilibrium. This is often associated with a leader-follower argument or a minorant game institution in which firm A moves first and firm B moves last, responding with the quantity that maximizes profit given the price quoted by A. In a repeat simultaneous move game, firm B might still be regarded as moving after B, in the subsequent period, so that the leader-follower posture could still emerge.

The traditional analysis yields the dominant firm equilibrium price (P_{df} = \$2.84) and corresponding quantities $Q_A = 6$ and $Q_B = 3$. This is obtained by assuming that firm B matches any price posted by A and chooses the quantity that maximizes B's profit.

In preparing this design, we calculated the joint profit matrix for firms A and B for a subset of the feasible prices that can be posted by them. In this matrix, if firm A posts the dominant firm equilibrium price, P_{df} = \$2.84, then the best response of firm B is also to post this price. At these prices firm A offers 10 units, firm B offers 3 units, and expected profits are (π_A, π_B) = (\$1.99, \$0.51) per period. Strictly speaking, this is slightly different from the dominant firm model profit shares, based on certain demand in which the large firm cedes the residual supply to the fringe. In our design, this would require seller A to limit Q_A to 6 units, and the profit shares would be (\$1.96, \$0.54) per period.

D. *Edgeworth Price Cycles*

Inspection of the joint profit possibilities also reveals the clear potential for an Edgeworth cycle in duopoly pricing. If the two firms start at the dominant firm equilibrium $(P_A, P_B) = (\$2.84, \$2.84)$, firm A has an incentive to cut price one cent to \$2.83. But this wipes out the profit of firm B, whose best reply is to match A's price, giving A an incentive to cut to \$2.82, and so on, until prices fall to $(P_A, P_B) = (\$2.79, \$2.79)$. At this point, A's incentive is to raise price back to \$2.84, with B then matching this price.

E. *Shared Monopoly (Tacit Collusion)*

If firms A and B are able to effect cooperation through price signaling, this strategy will be most effective if they (1) maximize joint profits and (2) divide this profit in a manner that will sustain the tacit "agreement" (the two firms cannot communicate except through the prices they select). The largest collective profit is for all production to be allocated to firm A, who charges the monopoly price $P_M = \$3.21$ and sells the quantity $Q_M = 5$, yielding $\pi_M = \$3.43$ per period for firm A. But in the absence of a mechanism for agreement, including an imputation of a share of this profit to B, there is no way to effect this outcome. Through signaling, it is conceivable that the two firms might work out an alternating sequence in which A and B take turns satisfying the whole market at their respective monopoly prices. This would yield a profit that averages one-half the monopoly price for each firm. Under this scenario we would have $(P_A, Q_A, \pi_A) = (\$3.21, 5, \$1.71)$ and $(P_B, Q_B, \pi_B) = (\$3.52, 3, \$1.29)$. A less sophisticated form of tacit collusion would be for the firms to post the same price and then share the market according to the demands realized via the random choice of firm made by each buyer in the posted-offer mechanism. At the shared monopoly price $P_M = \$3.21$, joint profit is a maximum, and $(\pi_A, \pi_B) = (\$1.80, \$1.21)$. But by defecting at a price one cent less, firm A can reap a substantial increase in profit. This is the case for all matching price strategies, and thus the maintenance of such strategies clearly requires cooperation by firm A. The same proposition holds for firm B except that the gains from defection are much smaller.

Since the CIS and CILS experiments did not yield any outcomes tending to support the attainment of a shared monopoly through tacit collusion, we doubted that such outcomes would be likely even in the present asymmetric cost design. However, we conjectured that under the PPAP treatment, tacit collusion would be more likely. Under this treatment firm A is constrained not to expand output for 2 periods after firm B enters, and any price reduction cannot be reversed for 5 periods. At a collusive high price this constraint makes it more costly for A to punish B for defection. Firm B, knowing that any cut in price by A cannot be reversed for 5 periods, may be hesitant to defect and risk being locked into a lower price pattern. Similarly, at low prices if A signals with a price increase, this action may have greater credibility under the PPAP for firm B and may increase the probability that B will follow.

F. *Relative Profitability of Alternative Outcomes*

Some of the debate on the appropriateness of predation models has centered on the profitability to the large firm of a predation strategy relative to alternative tactics. Two observations regarding this discussion relate to our experimental design. First, we note (McGee 1958) that one commonly proposed alternative to a strategy of predation is a buyout of firm B by A. This is *not* allowable in our particular design but could be incorporated into an extension of our design.[7] Second, notice that seller A makes a profit of \$3.42 per period as an uncontested monopolist, \$1.99 per period in expected profits as a dominant firm, from \$1.10 to \$1.80 per period in the competitive price range, and (at most) \$0.88 per period with a predation strategy. Thus, the reader should note that firm A's estimates of the direct profitability of predation depend crucially on A's expectations about firm B's exit behavior. Firm A's decision to pursue a predatory strategy depends, furthermore, on the profitability of predation relative to the profits A expects to receive if B stays in the market. Predation will look less attractive if firm A expects that the two firms will stabilize at a collusive price level near the shared monopoly price than if A expects that having B in the market will cause prices to collapse to the competitive range.

V. Experimental Results

We report the results of 18 experiments using the six different treatment conditions shown in table 1. Series 1–5, consisting of 11 experiments, imposed alternative conditions thought to be favorable (per-

[7] An obvious question is whether our prohibition against mergers makes predation more or less likely. If a buy-out is, as suggested by McGee (1980), a relatively attractive substitute for predation, then forbidding such a substitute strategy is consistent with our goal of creating conditions in which predation is relatively likely. However, Burns (1984) has suggested that in the case of the old American Tobacco Company, buy-outs may have been an integral part of a predatory campaign.

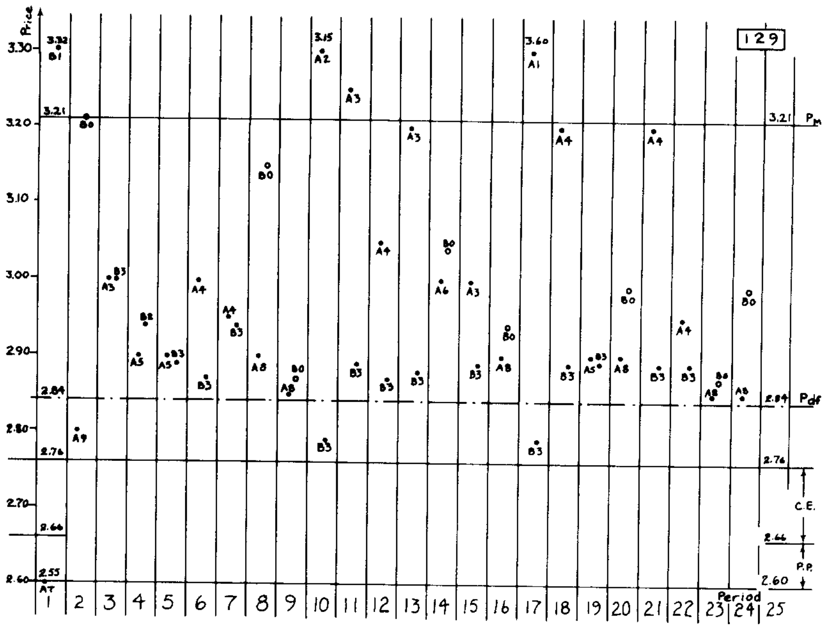

FIG. 2

haps progressively more favorable) to the emergence of predatory pricing behavior.

Figures 2–5 chart the sequential prices and corresponding sales quantities for one experiment from each of the series 1, 2, 3, and 6. Posted prices in each period are indicated by the solid and open circles. Thus in figure 2 (experiment 129) for period 8 the solid circle, denoted "A8," shows that A sold 8 units at the posted price, \$2.90. The open circle, denoted "B0," indicates that B sold zero units at the posted price, \$3.15. Periods such as 1–5 in figure 3 (experiment 135) show only the price posted by the incumbent seller A, indicating that seller B was not allowed to purchase a permit in periods 1–5. On all charts the monopoly price for A (3.21), the dominant firm price (2.84), the competitive interval [2.66, 2.76], and the potential predatory price range [2.60, 2.66] are marked on the far right. Finally, for experiment 153 subject to the PPAP, the heavy black arrow near the bottom of the chart denotes periods in which seller A has triggered a temporary price ceiling on himself through a reduction in price. The numbers along the arrow state the operative price ceiling.

Table 2 summarizes the performance of the 18 experiments. Each experiment is scored according to which type of pricing behavior was the plurality in the first 18 potentially contested periods: shared mo-

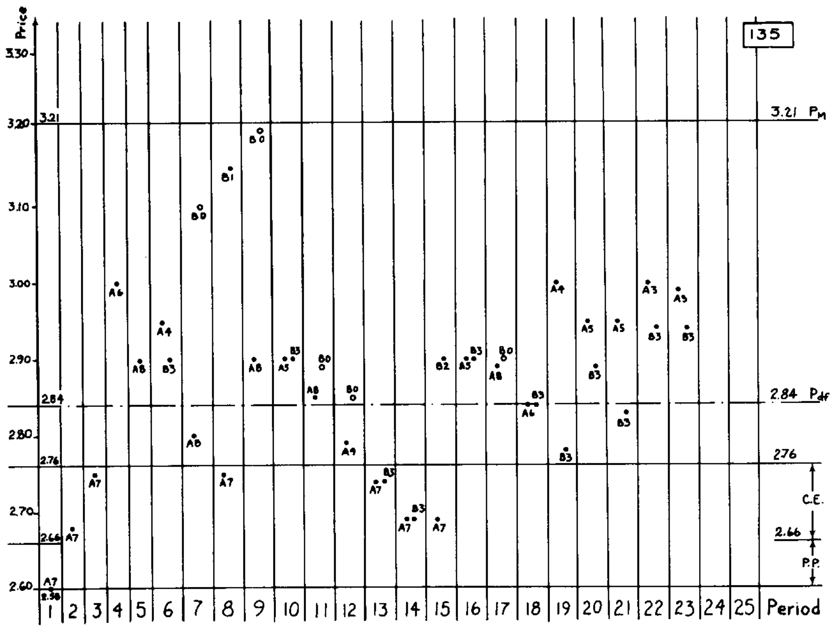

FIG. 3

TABLE 2

EXPERIMENTAL OUTCOMES

(Each Experiment Scored according to Plurality of Price Outcomes in the First 18 Potentially Contested Periods)

	PERFORMANCE HYPOTHESES			
TREATMENT SERIES	Shared Monopoly	Dominant Firm	Competitive Equilibrium	Predation: Predatory Pricing or Monopoly Pricing by a Surviving Firm
1	1 (133)	1½ (129, 131-tie)	½ (131-tie)	0
2	0	2 (135, 136)	1 (138)	0
3	1 (140)	2 (139, 141)	0	0
4	0	1 (142)	0	0
5 (confederate)	0	½ (2d half of 143)	0	½ (1st half of 143)
6 (antitrust)	5 (145, 146, 147, 149, 150, 152, 153)	2 (147, 149)	0	0
1–4 pooled	2	6½	1½	0

nopoly, dominant firm, competitive, or predatory (including both predatory pricing and monopoly pricing by a successfully predatory large firm). Since many observations are not precisely at any of those models' predictions, a simple metric was used in the scoring. Each price observation was counted as a hit for the model whose price prediction was nearest to the observation.

From table 2, there are two strongly supported general conclusions: (1) the absence of any predatory pricing behavior and (2) the radically different behavior of those markets conducted under the antitrust treatment rules. Each of these observations will be examined in more detail.

1. *The absence of predation.* We will summarize our experimental results by providing a brief narrative on each of the series 1–5, followed by a general discussion of all 10 experiments.

Series 1. We began our research with three experiments incorporating design features 1, 2, and 3. We found no evidence of what we had designated a priori as predation. The three large sellers posted 73 prices, and none satisfied our definition of predatory pricing.

There were three instances in which a large seller posted a price in the potentially predatory range. But, in each of these three cases, the large seller restricted quantity to 7 units, so the price was above both marginal and average cost. Each of these instances was in period 1, and none of the three large sellers ever repeated a price in this predatory range. It is perhaps arguable that this action can be interpreted as either (1) the early period price experimentation of a seller who does not have prior knowledge of demand or the costs of the rival or (2) a supersophisticated signal of a potential willingness to predate in the future. We are highly skeptical of the second interpretation, since all three instances occurred in period 1 and none was ever repeated. However, whether such strategic signaling behavior was in the minds of the large sellers or was capable of predatory interpretation by the small seller, the behavior does not match our interpretation of any consensus definition of predatory pricing, since price was not below average or marginal cost, and in each case the small seller picked up some residual demand and a rewarding profit.

Series 2. After our failure to observe predation in the first three experiments, we added design feature 4 (sunk entry costs) for the next three and introduced the incumbency treatment. Again, there were no predatory price-quantity pairs chosen out of the 69 observations. In this series, there were only two cases of a price posted in the potentially predatory range, and in both cases quantity was restricted so price was not less than marginal or average cost. In the experiments requiring that firms purchase an entry permit, we have a stronger test of whether large seller pricing activity can successfully signal predatory threats even if not at predatory levels. Of the 54 periods in which the small sellers could contest the market with a permit, they did so in all 54 periods.

Series 3. In these three experiments we went back to the drawing board to see what design features we might add to capture the phenomenon of predation. As described previously in Section II, we decided on design feature 5 (complete information). We speculated that if both firms were clearly aware of the advantages of the large firm, expectations might foster predation or the fear of predation leading to the exit of the small firm. We were wrong. None of the 69 decisions by large firms was predatory. Only *one* seller A's price was even potentially predatory, and it was, as before, accompanied by a quantity restriction. The small firm stayed in the market in 54 out of 54 possible periods.

Series 4 (experiment 142). Having failed to find predation in the first nine experiments, we wondered whether predation could be induced by the creation of "rivalistic" incentives having nothing to do with the underlying economic structure. To test this conjecture, we privately informed seller A that we would pay him $1.00 for each period in which seller B chose not to purchase a permit, The rivalistic seller never posted a potentially predatory price; in fact, only once did seller A post less than $2.83. The small firm never failed to purchase a permit.

Series 5. After 10 unsuccessful efforts to foster predation, we became seriously concerned that there might be some flaw in our design that was muting (what we assumed to be) the vulnerability of the small seller. Therefore, in experiment 143, we decided to push rivalry to its extreme point and choose as seller A a confederate (a graduate student), whose personal incentives were direct instructions to post predatory prices and quantities in periods 1–11. This fact was, obviously, concealed from the small firm. Seller B entered the market in period 6, was shut out in periods 6–10 (incurring the $1.00 permit loss), and refused to renew his permit in period 11. His decision not to reenter was reiterated to us at the beginning of period 12, and we signaled our confederate to begin to try to take advantage of his monopoly position. There is perhaps a strong clue to the weakness of the predatory pricing folklore in the subsequent behavior of our small seller. Despite being mercilessly pummeled by seller A, losing money, and twice deciding not to submit to such punishment again, seller B took only 1 period to look at seller A's price increase (period 12) and reentered (period 13) to capture some (perhaps transient) supernormal profits. That is, the difference in firm size and costs, economies of scale, nontrivial sunk entry costs, and an asymmetric deep pocket, combined with the actual experience of being forced out of the market due to losses, were not enough to preempt reentry when the predator attempted to take advantage of his newly established monopoly position. While we could have had seller A retaliate, in period 13 *alone* seller B earned \$1.32, which more than covered his reentry cost. This poses two obvious questions for further research. First, how much punishment in the form of retaliation by seller A is necessary to keep seller B from reentering? Does this required level of retaliation so weaken seller A's profit picture that seller A would be better off coexisting with seller B? Second, what would happen if seller B had to publicly announce an intention to reenter at least 1 period before reentry could occur?

General discussion of series 1–5. Although we observe no instances in which $P_A(Q_A)$ is in accord with our strict definition of predatory pricing, there are several sequences in which firm A's pricing behavior might be interpreted by firm B as having a predatory quality. For example, in experiment 135 (fig. 3), periods 7–9, firm A ignores firm B's repeated signal to raise the price. Then in period 10, firm B matches price with firm A, whereupon in periods 11–14 firm A repeatedly undercuts firm B's previous price. Firm A eventually seems to concede that this strategy is failing and engages in (fruitless) signals to raise price in periods 19–23. Similar results obtained in another experiment (140 in fig. 4). In both these experiments we can imagine that firm B might feel that he or she had been the victim of predatory behavior and might be tempted to file suit, given triple damage legal incentives and the vagueness of marginal cost in the nonexperimental world.

But if predation is not a satisfactory hypothesis for explaining firm behavior in this market environment, then a logical followup question is to ask which (if any) of the alternative hypotheses are being supported. Refer again to table 2 and the pooled results from series 1–4. (We exclude series 5, since it incorporated a confederate.) In these nine experiments, the modal (in fact, majority) observation supported the dominant firm prediction. Of the nine experiments, six-and-a-half were best described by the dominant firm model.

More evidence of the plausibility of the dominant firm model in this design can be seen by considering the confederate experiment (143). Beginning with period 17, we signaled our confederate to begin posting the pair ($P = 2.84$, $Q = 6$), which is the large firm's dominant firm strategy. We wondered if this behavior would indeed attract seller B to his competitive fringe strategy ($P = 2.84$, $Q = 3$). The answer was yes. This suggests that the leader-follower flavor of the dominant firm model can be captured in an iterative environment in which, technically, both firms move simultaneously in any 1 period.

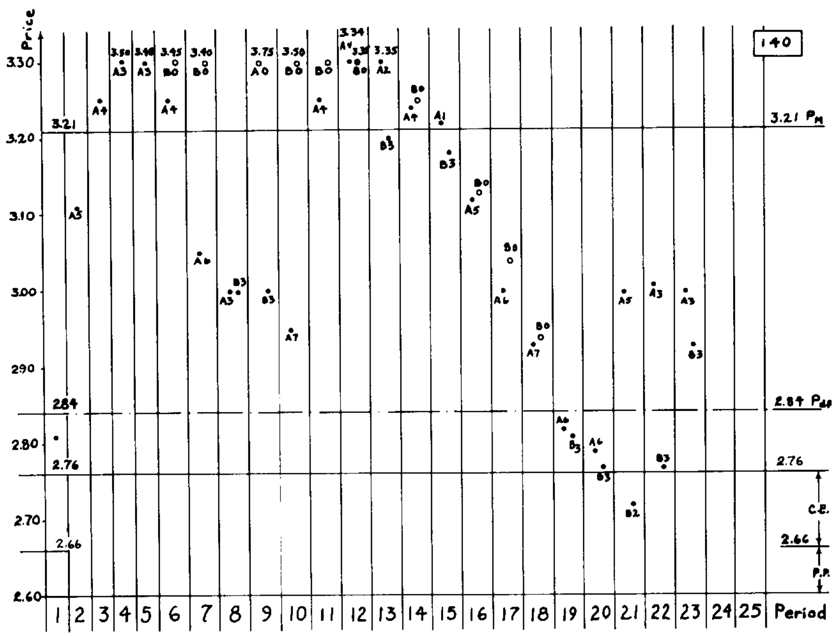

FIG. 4

One shortcoming of the mutually exclusive fourfold categorization of table 2 is that it does not account for our fifth alternative hypothesis, the Edgeworth cycle. This is because these cycle prices include $2.84, the dominant firm price. Yet it would be useful to ask whether the eight experiments in series 1–4 that were scored either "competitive" or "dominant firm" were being driven by the dynamics suggested by the Edgeworth model. One arbitrary measure is to ask whether the runner up, or second place outcome, in the two categories (competitive, dominant firm) accounted for as many as one-third of the number of observations as the primary category. If the answer is yes, this indicates a lot of activity between the competitive and dominant firm prices, which is at least consistent with the Edgeworth model. If the answer is no, this could indicate either acyclical (equilibrated?) behavior or cycles outside the Edgeworth range (perhaps cycles of success and failure in firms' attempts to establish tacit cooperation).

Using the categorization above, one finds that only two of the first 10 experiments, 131 and 138, can be classified as Edgeworthian. The others show no single consistent pattern. For example, one experiment (141) converged very closely to the dominant firm prediction while another (129 in fig. 2) appeared more unstable. Its cycles away from the dominant firm price tended to be toward the monopoly rather than the competitive prediction.

2. *The effect of antitrust procedures in series 6.* The seven experiments incorporating our PPAP were all conducted with design features 1–4. Thus, in the absence of the antitrust rules, the treatment is that of series 2. This raises the following question. When one discusses the effects of antitrust rules, what is the appropriate control sequence? Is it just series 2, or is it the pooled results from series 1–4? Series 2 by itself is the more exact structural control, but there are only three observations. Pooling adds more information, and the results from 1, 3, and 4 seem consistent with 2. But pooling runs the risk of introducing some specification error. We therefore will report both comparisons. It happens that the qualitative results are robust with respect to the pooled or not-pooled control.

The fundamental conclusion from our series 6 experiments is the existence of a type 2 regulatory error. That is, adding rules against predation in an environment where predation might be expected to occur may not be benign. Our results show a performance that is less competitive and less efficient with the safeguards against predation in place.

This qualitative result can be seen in at least three different ways. First, the effect can be seen at a glance in the data of experiment 153 (fig. 5), which vividly demonstrates the most extreme example we observed showing how the antitrust rules can provide incentives for tacit cooperation near the monopoly price and quantity.

Second, refer again to the classification of the experiments in table 2. Suppose we combine the observations so that we count each experiment as either (i) a shared monopoly or (ii) not a shared monopoly. The proportion of shared monopolies in series 6 is .71 while in series 2 it is zero. (A χ^2 test on this difference in proportions is significant at $\alpha = .05$.) Comparing series 6 with the pooled proportion of series 1–4, one gets .71 against .20 (which is also significant at $\alpha = .05$). Thus, we can reject the hypothesis that there was no shift toward shared monopoly outcomes when the PPAP rules were applied.

Third, one can examine directly the efficiency criterion of market performance. In figure 6, we have graphed the period-by-period measure of what we call "quasi efficiency." (This measures the ratio of realized surplus obtained by the participants to the maximum possible surplus, without attempting to amortize into this ratio the cost of the entry permits where they were required.) A fully competitive market would be 100 percent efficient by this measure. A fully rationalized cartel would score 72.5 percent. Again, a comparison of the charts in figure 6 is striking. In every period, the markets with PPAP per-

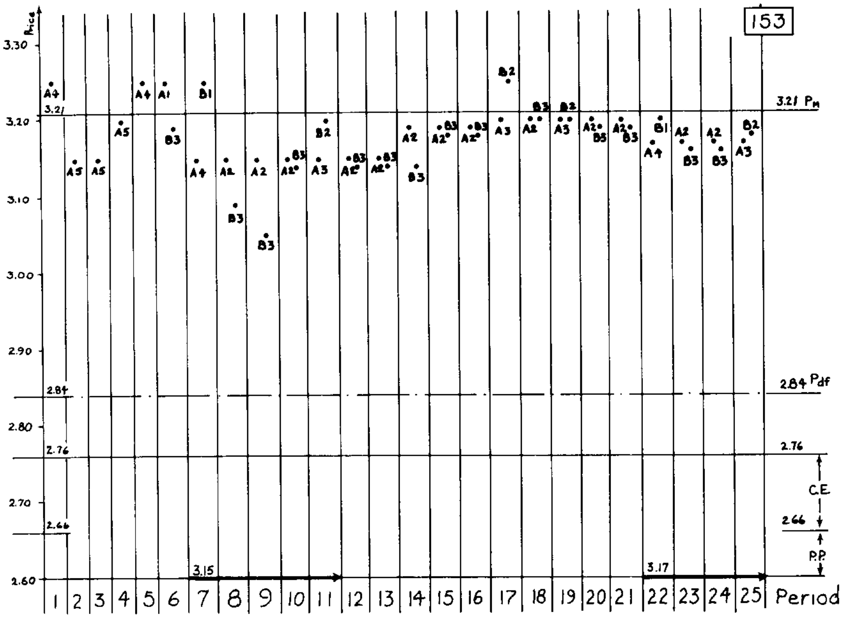

FIG. 5

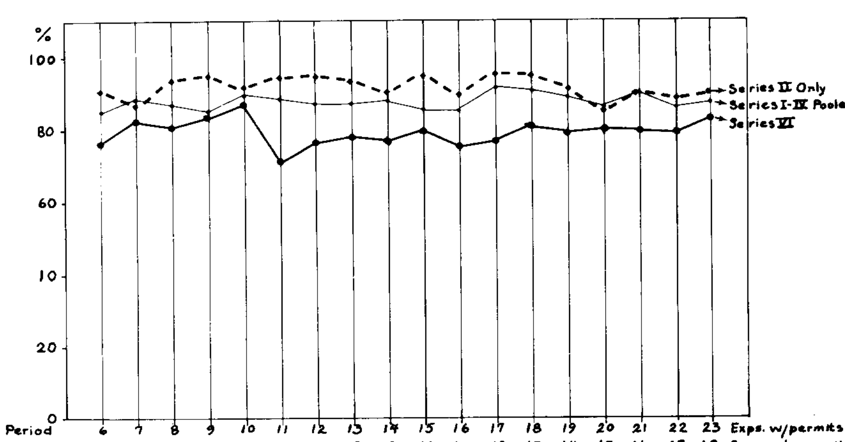

FIG. 6.—Market quasi efficiency in first 18 contested periods (i.e., does not attempt to amortize permit costs).

TABLE 3

TESTS OF MEAN EFFICIENCIES WITH AND WITHOUT ANTITRUST RULES IN EFFECT

	Based on All 18 Contestable Periods	Based on Last 5 periods
Control is series 2 alone	Difference = −12.17% $t = -2.00$*	Difference = −8.25% $t = -1.57$
Control is pooled series 1–4	Difference = −7.91% $t = -1.89$*	Difference = −7.37% $t = -2.056$*

NOTE.—Negative numbers indicate reduced efficiency with antitrust rules.
* Significant, $\alpha = .05$.

formed less efficiently, on average, than the markets without this treatment (using either series 2 or pooled series 1–4 as the control). A statistical test of the significance of this difference is presented in table 3. We present four t-tests on the difference in efficiencies in 2×2 dimensional form. Two of these tests use series 2 data as the control; two use pooled data from series 1–4. On the second dimension, two tests use the mean of all 18 potentially contested periods as the base and two use the mean of only the last five (this latter was a measure introduced in CILS). In all four cases the direction of the difference shows lower market efficiency with the antitrust rules. In three of the four tests, the difference is significant using a one-tailed t-test at α = .05.

VI. Conclusions

Based on the results of 11 predatory pricing experiments, our principal conclusion is that, so far, the phenomenon has eluded our search. We are unable to produce predatory pricing in a structural environment that, a priori, we thought was favorable to its emergence. The predominant outcome is that of the dominant firm equilibrium. These results would appear to be consistent with Selten's (1978) game-theoretic analysis of predation in which such a strategy is inconsistent with the perfect equilibrium solution concept. By backward induction at each stage, predation does not pay. At each stage an entrant knows that if it enters and is preyed on it would have been better not to enter. But this expectation is offset by the potential prey's also knowing that with actual entry the incumbent is better off not to predate. Thus it is rational throughout the history of the market for the incumbent not to predate and for the potential prey to enter.

Where next in the parameter space should one look for predatory pricing? We suspect that more work on rivalistic behavior might be fruitful. Although our one attempt to introduce rivalistic incentives failed to yield a predatory outcome, we still think this is a direction of search that might have good results. This direction abandons the concept of rational predatory action and is contrary to the mainstream economic theory exercise. It also abandons the objective of asking whether predatory behavior will arise "naturally," as a human trait, in the laboratory. To deliberately induce rivalistic behavior is to assume that such behavior exists in the field but for some reason has not been manifest in the laboratory. This calls for harder evidence on the mainsprings of behavior in alleged predatory cases in the field than we have been able to discern in the literature.

A second potentially promising direction is suggested by the game-theoretical literature on reputation (Kreps and Wilson 1982; Milgrom and Roberts 1982). In this literature Selten's paradox (the inconsistency of predation with perfect equilibria) is resolved by an imperfect information assumption—either that agents are uncertain of the payoffs of their fellows (Kreps and Wilson 1982) or that they are uncertain whether such payoffs are uncertain (absence of common knowledge) (Milgrom and Roberts 1982). These assumptions lead to models of rational predation in which it pays an incumbent to predate following entry because the resulting reputation deters future entrants and these future benefits outweigh the earlier short-term losses. Of course, the imperfect information assumptions were part of our experimental design, and reputation effects did not arise naturally. However, our use of a confederate in one experiment could be expanded to attempt consciously to create reputations of the type investigated in these models. Again, this involves a departure from the search for naturally occurring behavior that is predatory, and the justification for this raises methodological issues that have not been examined in any depth.

We think there is a sense in which all of the existing predatory models, as well as our experimental design, are deficient. Entry requires capital investment, exit implies divestiture, and (with the exception of general purpose broadly marketable capital, like trucks) the value of an entrant's capital stock should not be assumed to be independent of whether predatory pricing occurs. If the capital stock is specialized (e.g., railroad track), an exiting prey will surely not be able to recover more than a fraction of replacement cost from any potential new entrant. But this means that a new entrant can buy in as a competitor at a capital cost that has already discounted the expectation of predation. Hence some profitability is assured a new entrant, while if predation is discontinued, supranormal profits will be enjoyed. Unless the predator buys the discounted capital stock of the prey (Burns 1984), predation merely bankrupts the prey firm but fails to eliminate the existence of a competitor. Bankruptcy gets rid of incumbent management, not capital assets, which are reallocated to new managers.

The results from our seven experiments with the predatory pricing antitrust rule form the basis for our second major conclusion. We have evidence for the existence of a type 2 regulatory error. The antitrust regulations imposed on a market that might be thought to be susceptible to predatory pricing caused the market to perform less competitively and less efficiently than in the absence of any regulations against predation. We cannot say that any regulations against predatory pricing would have this effect, although these results graphically display the potential for efficiency losses from programs providing for output expansion limits combined with rules requiring semipermanence of price reductions. More generally, we believe that these results emphasize the necessity for public policymakers to realize that any remedies designed to correct alleged market deficiencies may provide counterproductive incentives. Their task may become one of evaluating various proposals on the basis of which one might result in the largest net benefit, not which one corrects a particular defect.

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